# Coal: A Neglected Resource - Making the Best of it for the Future

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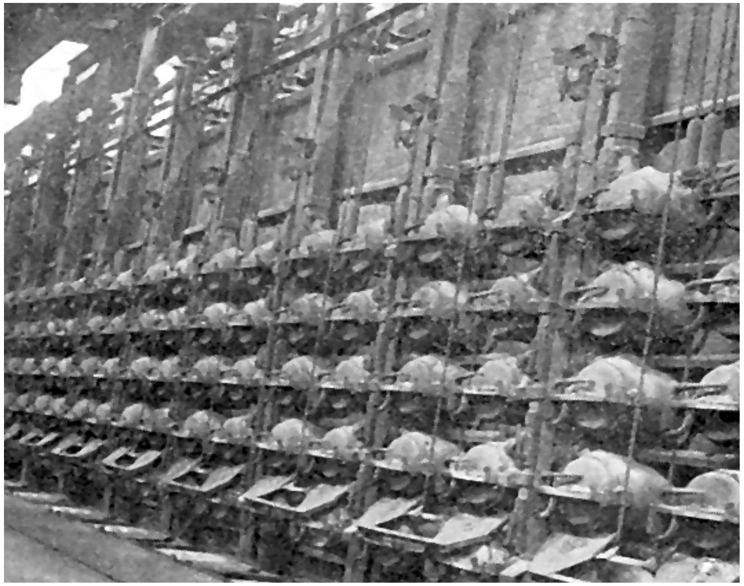
# Overview

1. Coal through the ages
2. Uses of coal with R&D indicated
    - 2.1 Power Generation
    - 2.2 Gasification
    - 2.3 Liquefaction
3. Projections
4. Conclusions

# 1. Historical

- Charcoal used for pig iron
- Deforestation caused  switch to coal
- 1620 coke oven production first recorded
- 70% of global steel now depends on coal

- Coke: a Chinese article of trade > 2000 years ago
- Coal probably used in the iron ages
- 13th century coal used in England for forging iron



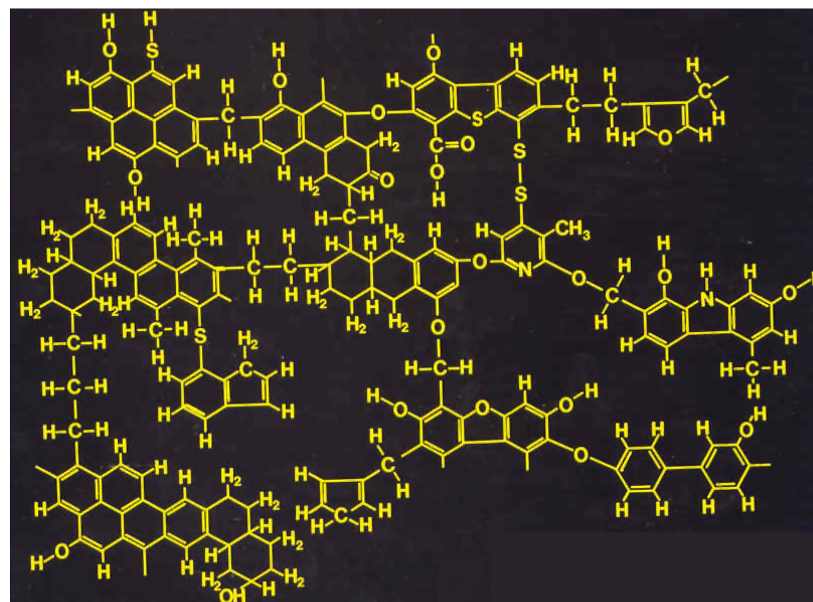
- 1792 Murdoch proved gas can be generated from coal
- Town Gas : London 1814

# Coal Chemistry

**Glauber's "Philosophical Oven" 1652**

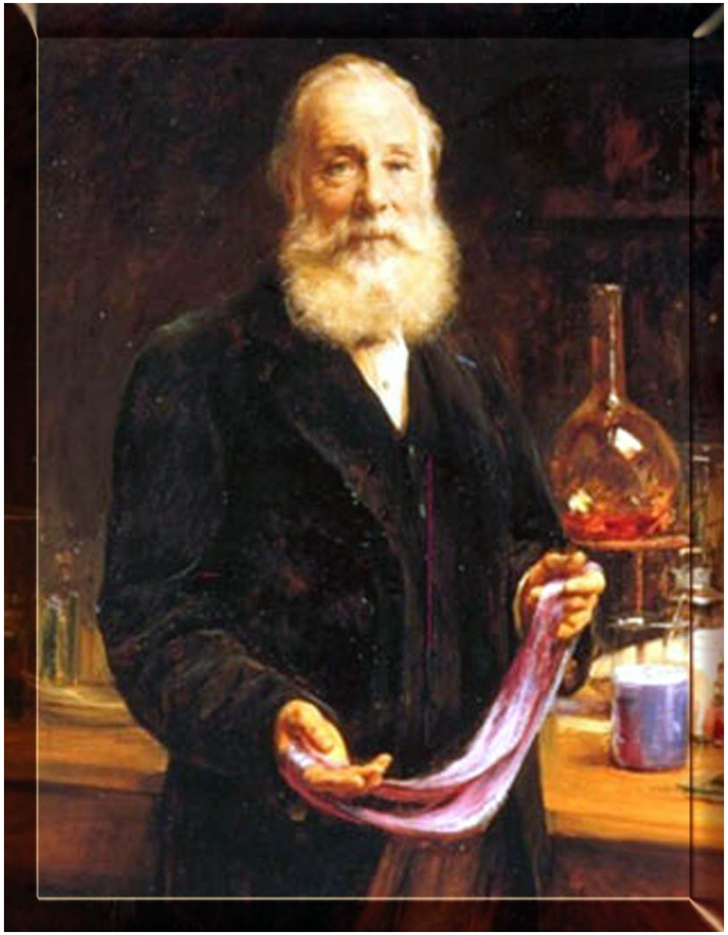
**Dry coal distillation (tars, oils, aromatics, char)**

**Up to middle 1800's coal tar regarded as waste**



# Coal Chemistry

- Dyestuffs: the roots of organic chemical synthesis
- Perkin 1856: “aniline purple”
- 50,000 dyes by 1900
- 1913 Germany controlled 90% of coal derived dyes
- Start of multinational petrochemical companies
- Coal science developed in its own right
- Analytical chemistry made big strides



# Other Coal Based Spin – Offs

- Creosote for railway ties
- “Tar asphalt” for roads
- Technical carbon for electrical/ electronic applications
- Carbon black in tires since 1912
- Graphite plates for chlor-alkali industry
- Activated carbons
- Derivative chemicals: fertilizers, acetic acid, acetates, methanol, solvents, lubricants
- Phenolics and cresylics
- US Coal tar now less than 1/3 of 1950 production

# 2. Main Uses of Coal

- Combustion to produce steam/power
- Gasification to produce syngas ($H_2$ with CO)
  - Syngas to fuels (Indirect Liquefaction)
  - Syngas to chemicals, including methanol
  - Syngas to hydrogen
  - Syngas to synthetic natural gas (SNG)
- Direct coal liquefaction (Not covered here: not commercial)
- Co-production ("polygeneration")
- Gas to Liquids (GTL) same as second part of Coal to Liquids (CTL)
- Industrial uses – steel etc (not covered further)

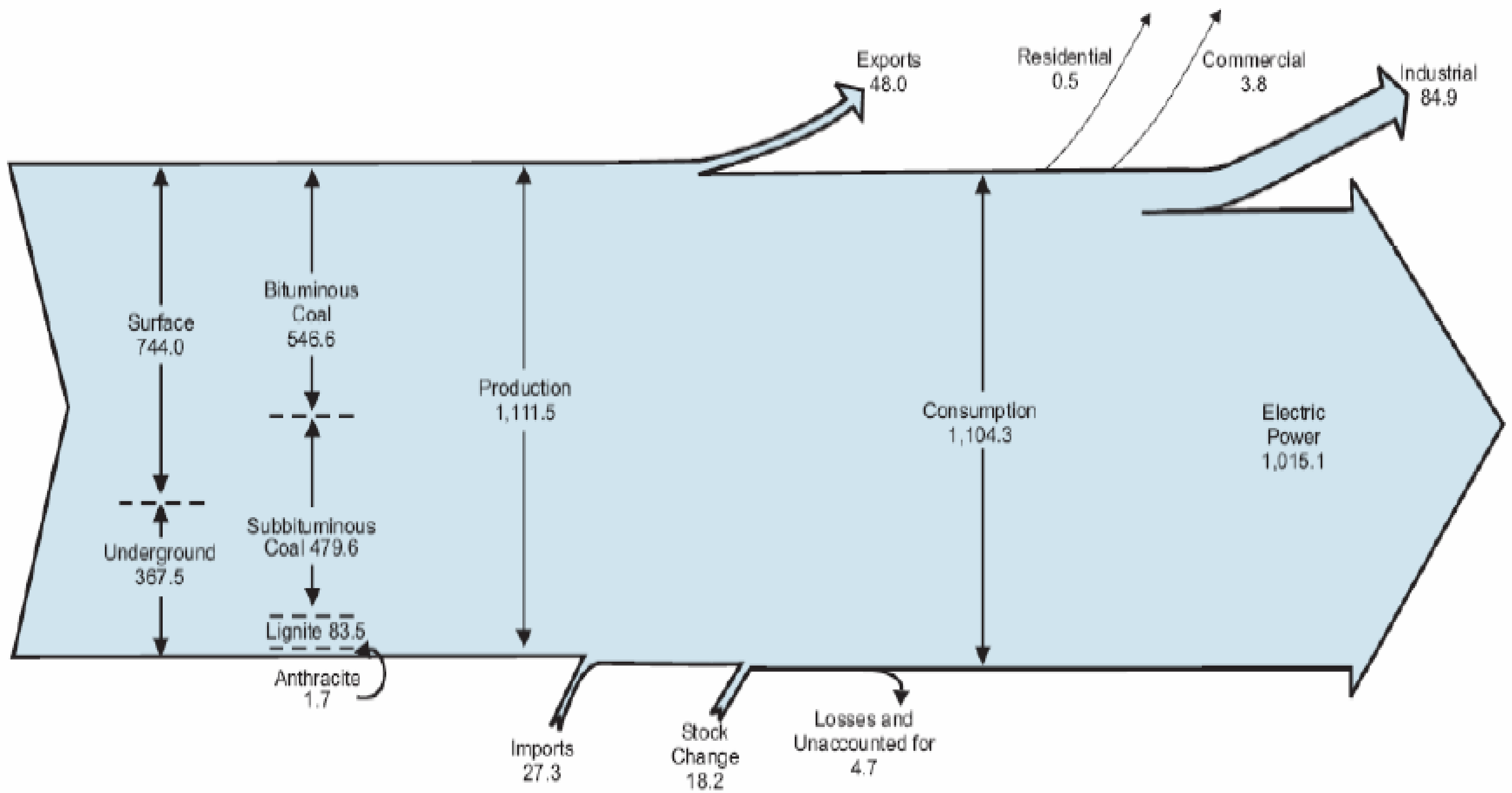
# USA Situation

- National Coal Council Report March 2006

  http://www.nationalcoalcouncil.org/

- USA has 27% of the world's coal reserves
- Power generation from coal dominates
  - 52% of US power is from coal
  - 91% of mined coal goes to power generation

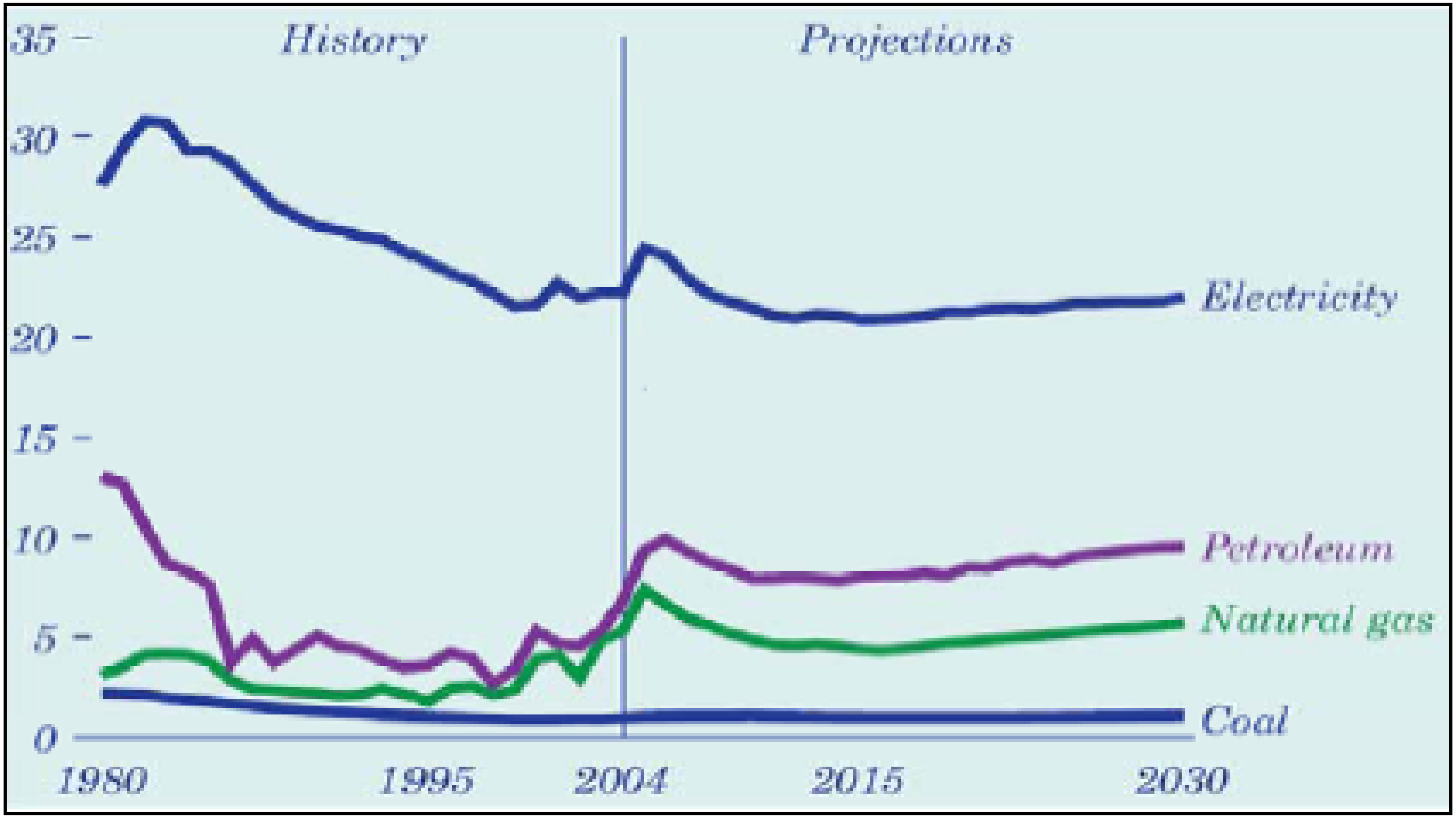
# Coal Flow in the USA




Source: 2006 EIA Outlook

# Energy Prices 1980 – 2030

## 2004 $/Million Btu




Source: 2006 EIA Outlook

# Coal Use Grows While Emissions Decline

Coal Used for Electricity Has Tripled
Since 1970 While Emissions Have Been Significantly Improved

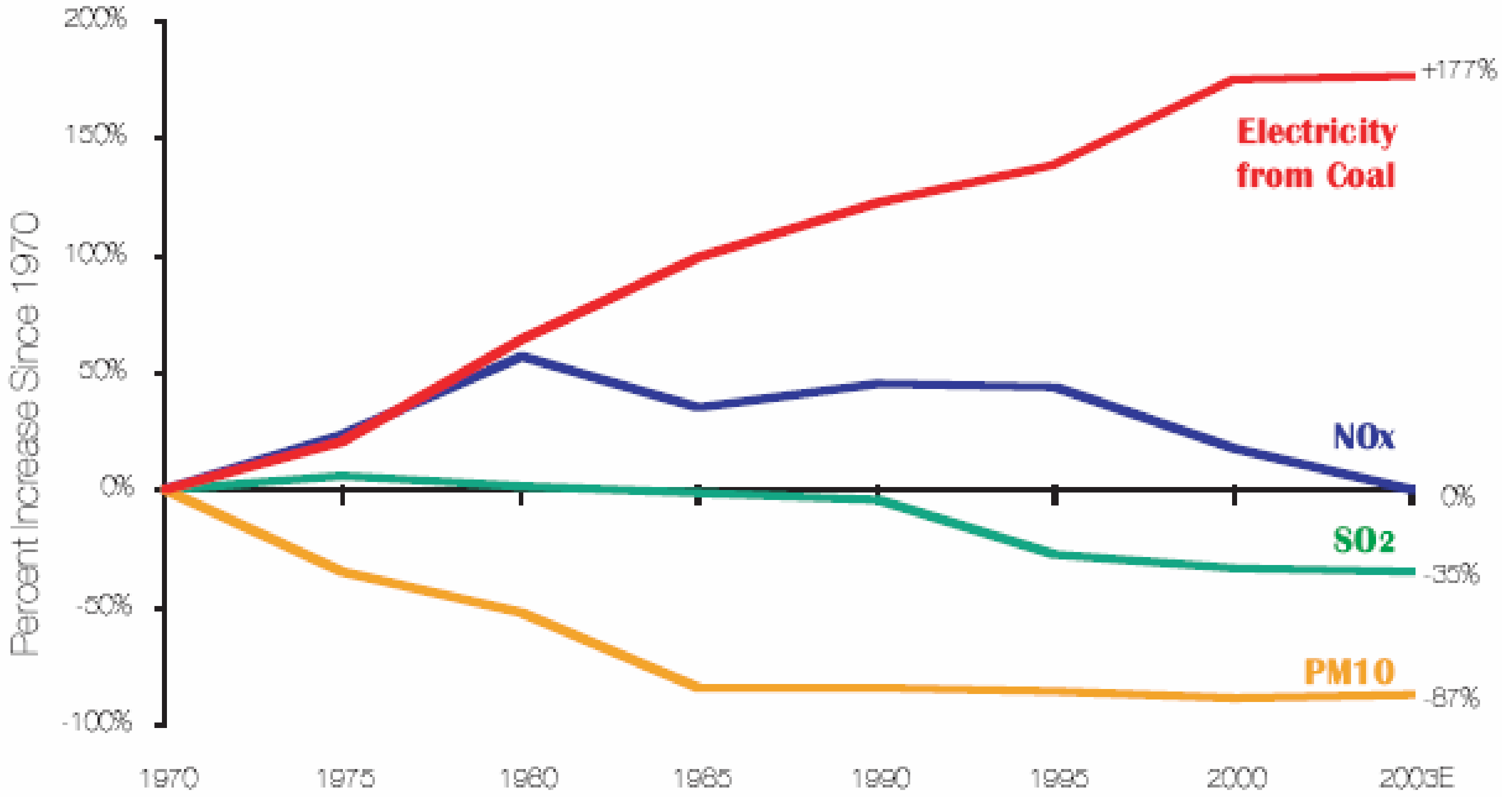
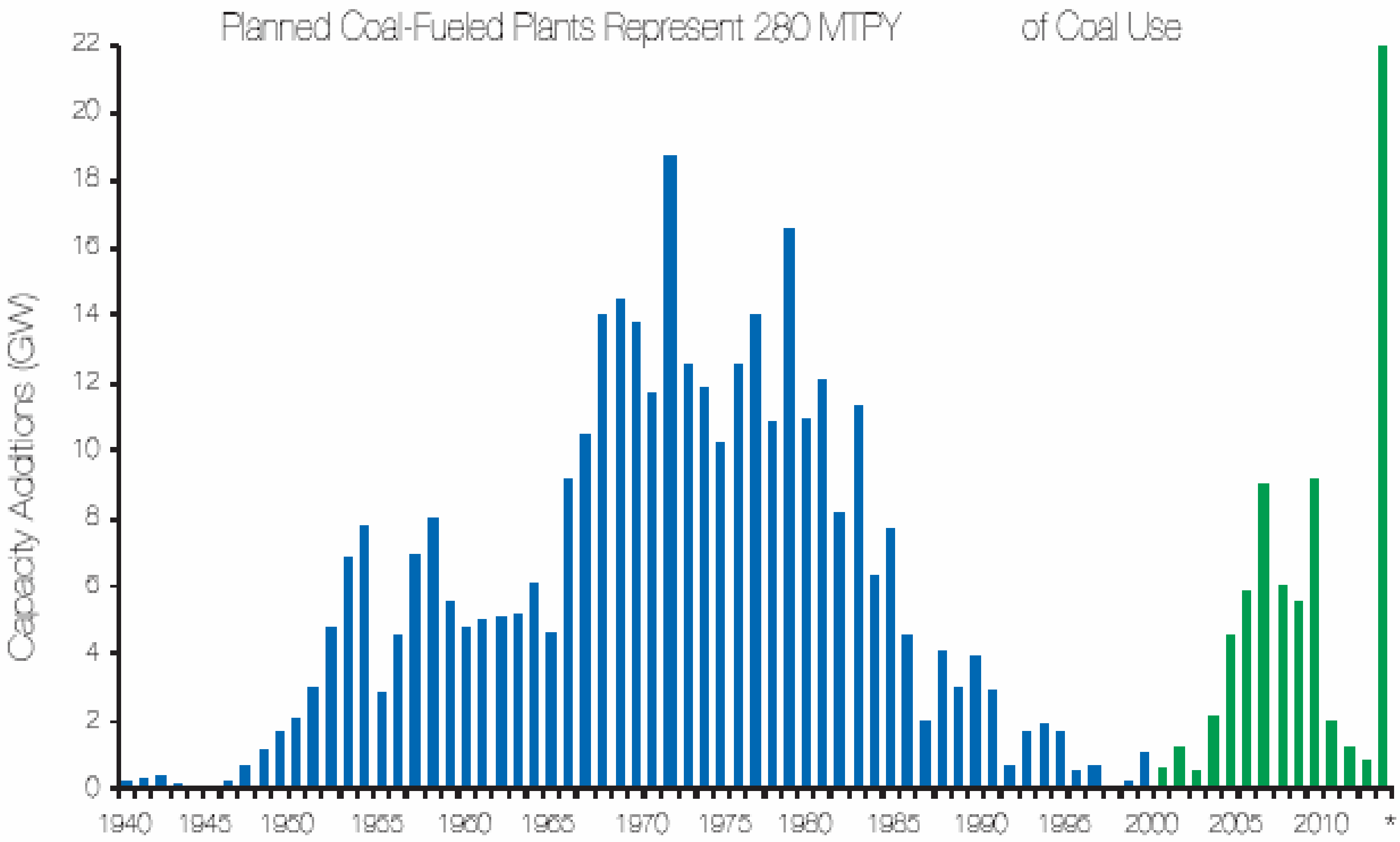



**Figure ES.2** Source: EPA National Air Pollutant Emission Trends Dec 2004: EIA Annual Energy Review 2003 (September 2004)

# 2.1 Power Generation

- Few coal fired power stations built in recent past – gas believed to be cheap, plentiful and clean
- Future: carbon taxes and global warming issues critical
- Nuclear power for power generation (currently about 20%) likely to increase but slowly
- More recent combustion technologies:
  – supercritical and ultra-supercritical steam systems for high efficiencies
  – fluidized bed combustors
  – circulating fluidized bed units

# U.S. Forecasts Largest Increase in Coal Generation in Decades




* Timing not yet committed.

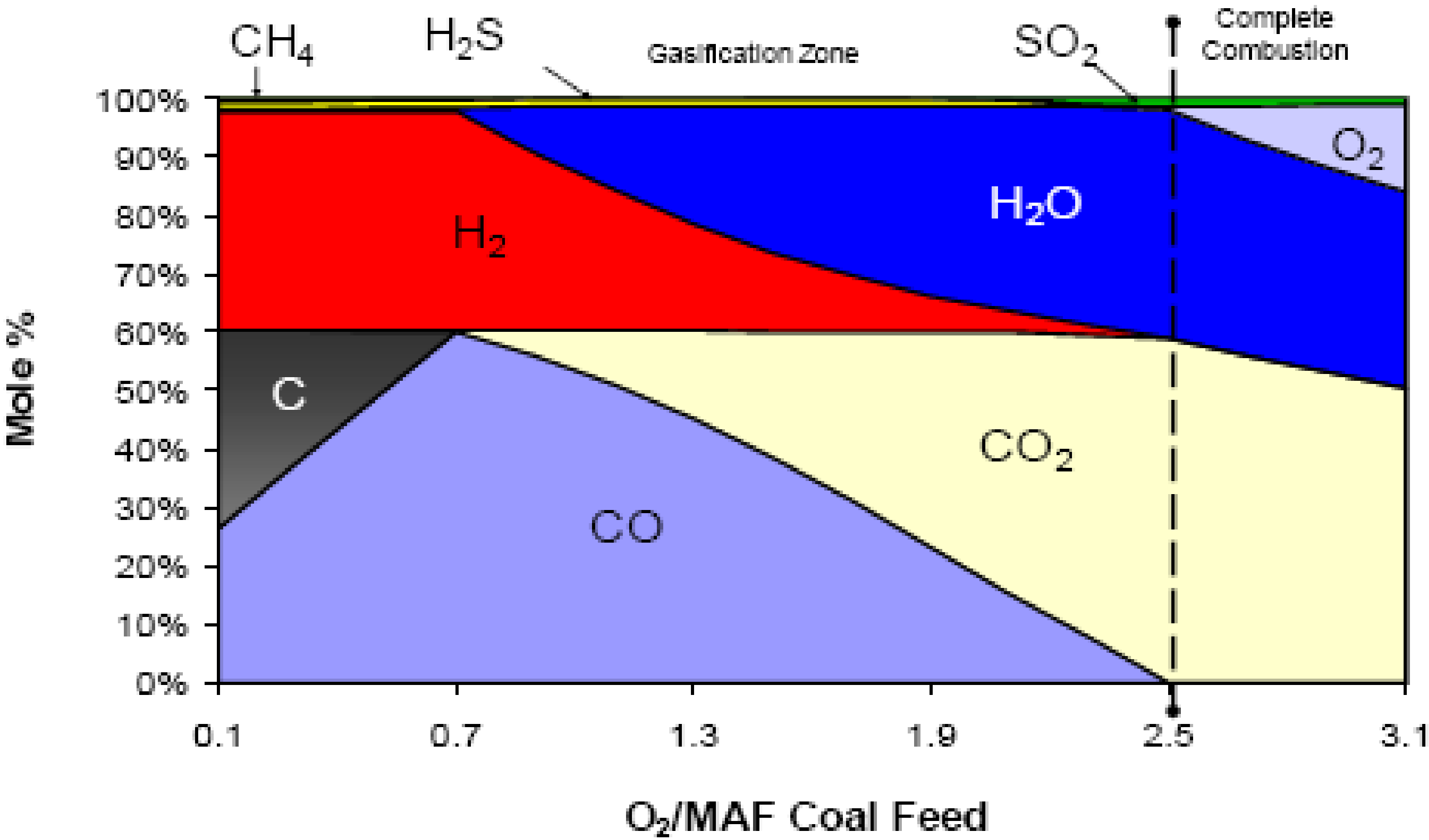
Figure ES.3 Source: DOE, National Energy Technology Laboratory, 2006

# R&D Needs Related to Coal Fired Power Generation

- Environmental improvement
- Efficiency improvements
- Construction materials for high temperatures and pressures
- Sensors and controls
- Ash disposal and utilization
- Further development and commercialization of IGCC (Integrated Gasification Combined Cycle) systems, including turbines
- Fuel cells as co-producing units
- See DOE and CURC Roadmaps and web sites

# Combustion and Gasification

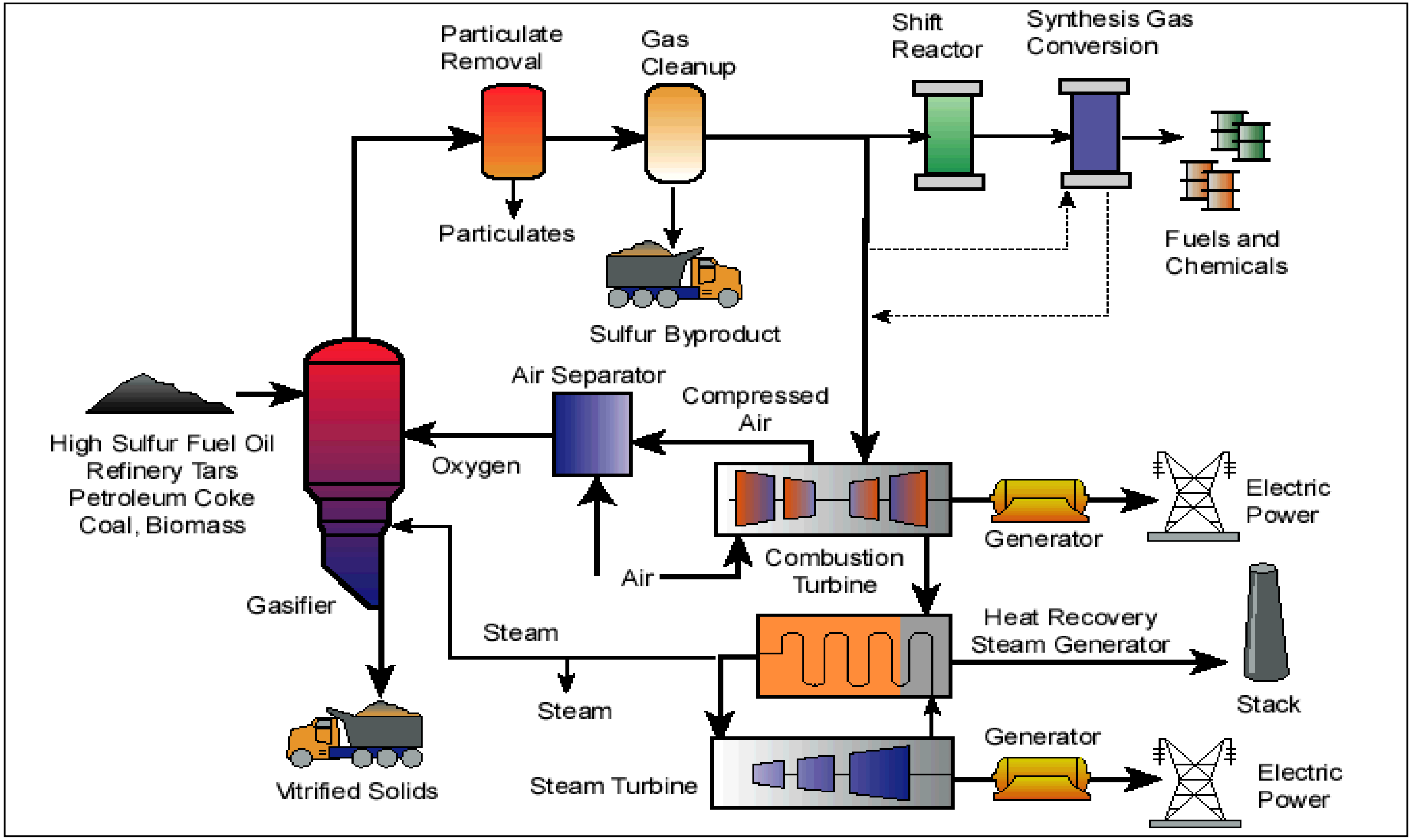
## Gas Composition as fn ($O_2$/Coal)



# 2.2 Gasification

- Sub-stoichiometric combustion: leads to CO +$H_2$ ("Syngas")
- Many different commercial gasifiers applied world-wide but few built in the USA so far (Four facilities)
- For power generation: growing interest in IGCC for clean power generation with $CO_2$ capture potential
- Syngas a very versatile building block:
  - Methanol, DME, Acetates, Olefins etc
  - Fischer-Tropsch products; fuels and chemicals
  - $H_2$, $NH_3$, Fertilizers
  - SNG via methanation

# Basic Gasification Flowsheet



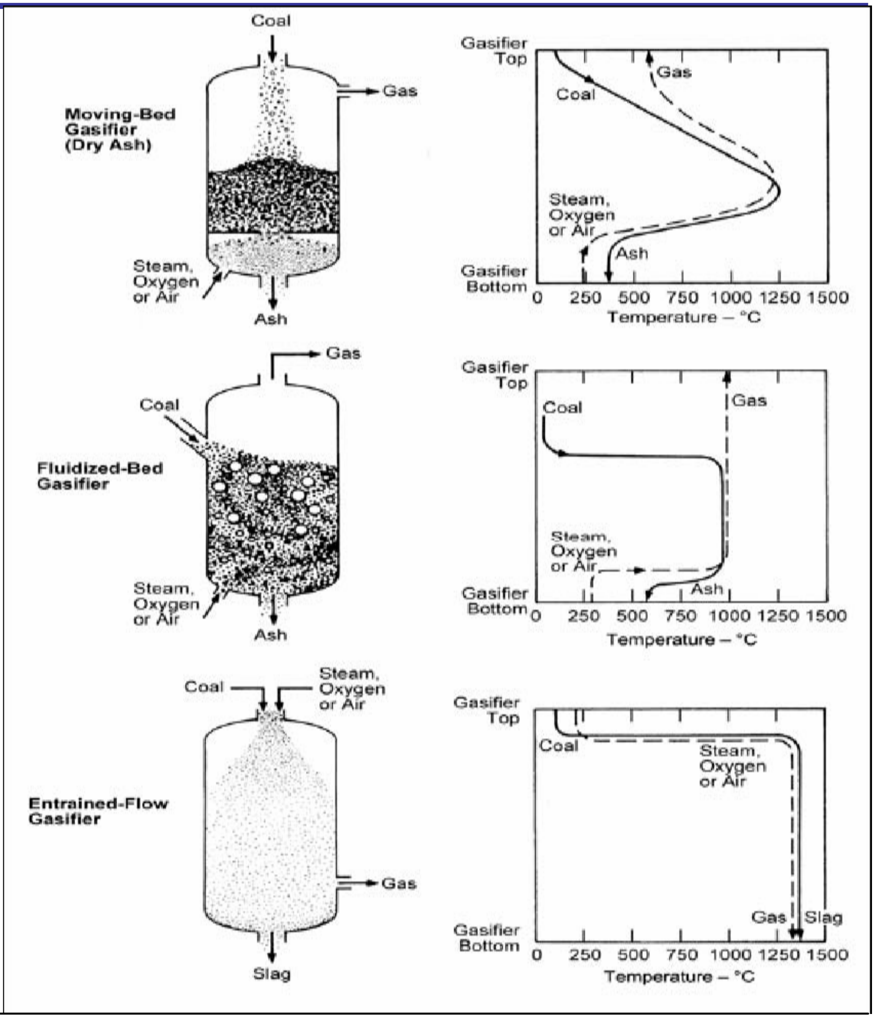

Source: GTC web site

# Main Gasifier Types

1. **Moving Bed**
   - **– Dry Bottom shown (Lurgi)**
   - **- Slagging Bottom as a variation (BGL)**

2. **Fluidized Bed**
   **(Winkler and others)**

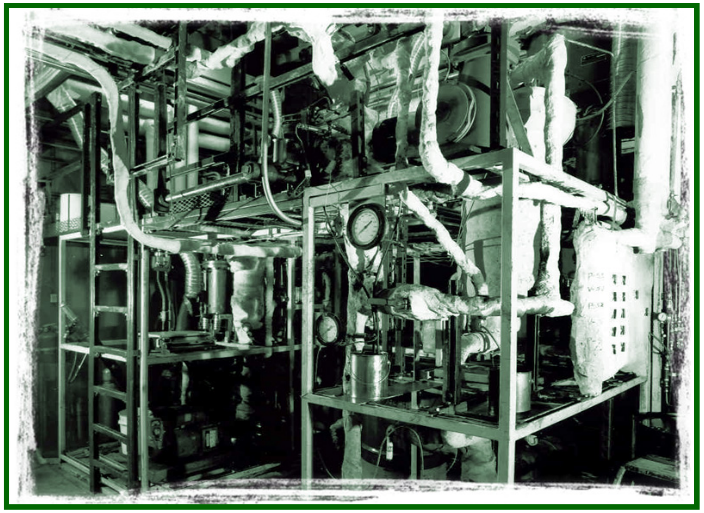
3. **Entrained – Slagging**
   **(GE/Texaco, E-Gas, Shell)**



# R&D for Gasification

- Refractories
- High temperature materials of construction
- Control systems
- Novel (cheaper) concepts
- Lower cost of producing syngas
- Feed systems: all coal grades; biomass; wet and dry
- Slag removal and application/uses for by-products
- Heat integration systems
- Turbine developments
- Improved gas clean-up: $H_2S$, COS, Hg, $CO_2$ and particulates
- Syngas to synthetic natural gas through methanation
- Entry into large scale hydrogen production

# 2.3 Coal Liquefaction: Two Methods



Indirect: coal gasified with steam and oxygen and resultant CO and $H_2$ (syngas) is catalytically converted to liquid hydrocarbons at about 375psi (25 bar) and 400-630°F (200-340°C)

Direct: fine low-ash coal with catalyst; high pressure (3500psi/230 bar+) and temperature (750°F/400°C) reacts with hydrogen to produce liquid hydrocarbons and char-like residue

# Indirect Liquefaction: Fischer-Tropsch

- Invented 1920's
- South Africa saw opportunity in late 1920's
- Developed pre WW II Germany
- Sasol commercialized FT in South Africa 1955 and again 70's and 80's: only commercial CTL in the world and expanded into chemicals to improve profitability
- Other ventures built based on natural gas (GTL), Shell, PetroSA
- Sasol experience of 50 years: >200 different products; cumulatively >1.5 billion barrels of fuel; Synfuels 28% of South African transportation fuels demand.
- Coal based: commercially less attractive for new investments than gas based

# Sasol Plants At Secunda ~ 1985

Initial capacity: 2 x 50,000 bbl/d, Then 40% of SA's fuel needs, now 28%; Cost $6bn; Site ~3,200 acres

Two plants built sequentially with $500m saving

Construction work force 28,700; 250 million man-hours.

Now 160,000 bbl/d

# Sasol GTL Oryx Project in Qatar

- Two reactors 60 m high, 10 m diameter; @2,200 tons
- Project expansion to add 66,000 bbl/d fuels and 8,500 bbl/d lubricants
- 34,000bbl/d plant to be commissioned June 6, 2006

# R&D: FT Product Work-up

Final product spectrum:

- Depending on type of reactor and catalyst, the products can be primarily diesel or gasoline and chemicals with a wide range of options
- Can be adjusted in wide ranges but need to be set more narrowly at engineering design stage
- Potential for value addition: preferably as spin-offs and not as part of key base load justification
- Market driven product spectrum – use for naphtha
- Modeling aspects of the FT system and the overall highly integrated production process with extensive utility and power generation options

# R&D Aspects of CTL Products: Diesel

- Generically: Primary product zero S, minimal aromatics
- Predominantly straight chain (high cetane number >70)
- Fuels fully compatible with existing fuels: logistics and infrastructure advantages for FT fuels
- Suitable for aviation/jet fuels
- Potentially a high $H_2$ content energy carrier
- Emission from diesel engines but greatly superior to even CARB diesel performance
- Excellent blending stocks

➔ Potential for niche and bulk product applications research

# Economics: Capital Cost: R&D Impact

CTL capital investment (Sasol 2006)

For 50,000 to 80,000 bbl/d green field cost $60,000 to $80,000 per daily barrel ($3 to $6 Billion) – But: site specific

(Note: GTL ~$30,000/dbbl)

Production costs

Can produce finished products at about $45-$50/bbl (crude equivalent: $35-40/bbl)

Yields: Typically 2 barrels per ton, depending on coal

i.e. for 80,000 bbl/d about 15 million t/year coal

➔ R&D can reduce capital costs through reduction of capital investment, e.g. construction materials, control systems, plant integration/optimization

# Why the Great Interest in CTL in the US Today?

- Supply and demand of liquid fuels internationally very tight – China and India; declining reserves
- Consequently high gasoline prices
- Crude oil supply from high risk locations
- Coal prices increased, but coal much cheaper than other energy sources
- Abundant coal reserves
- Potential entry to the hydrogen economy via gasification

# Some Hurdles to CTL Commercialization

- Hurdles are not insurmountable: can be done again and can make money
- Energy Policy Act of 2005 a point of departure - Government facilitates and provides incentives
- Economic uncertainty and perceived high risk for high capital layout
- More plants required to obtain comfort for financiers
- Large companies reluctant to lead commercialization
- Many studies done but inadequate open literature data on actual plants available to validate economics
- Some lessons are only learnt at large scale
- It requires a national will and strategy

➔ Economic concerns dominate but R&D can contribute to improved viability

# 3. Projections to 2025: NCC Report

**Capital Expenditures for Coal Btu Conversion Technologies**

| | Coal Use Per Year in Million Tons | Capital Expenditures in Billions (2005 Dollars) |
|---|---|---|
| Coal-to-liquids | 475 | $211 |
| Coal-to-gas | 340 | 115 |
| Coal-to-electricity | 375 | 150 |
| Coal-to-hydrogen | 70 | 27 |
| Coal for ethanol | 40 | 12 |
| **TOTAL** | **1,300** | **$515** |

Figure ES.5

Current coal production about 1.1 billion t/year

Additional needs 1.3 billion t/year

Economic multiplier: Over next 20 years it will contribute to

- 1.4 million new jobs
- GDP gains of $3 trillion

Some concerns:

Impact on mining

Impact on the environment

Transportation of coal

Skills

# 4. Outlook for Coal Research

- Coal as an abundant resource will be used for many years: we need responsible ways of doing it
- Environmental aspects, including $CO_2$ capture and sequestration are key to the success with consideration of efficiency, conservation and stewardship: "Cradle to grave"
- Understanding the fundamentals of coal chemistry can lead to new applications and materials
- Chemistry, catalysis and material science underpin much of the research needed
- Enabling research should lead to new technological options
- Better understanding of fundamentals and modeling lead to process and design optimization and cheaper products
- Additional research provides a greater pool of very necessary human resources in this area

# Action

Step out and take on the challenges which the current circumstances offer us to use coal cleanly and efficiently:

Research <u>and</u>

Development <u>and</u>

Demonstration <u>and</u>

Deployment/Commercialization

➔ Accelerate the pace